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DESCRIPTION

RADAR

Technical Field

The present invention relates to a radar for scanning a beam over a predetermined scanning range.

Background Art

A millimeter-wave type of car-mounted radar that varies the beam azimuth over a predetermined scanning range has been developed. This type of radar transmits and receives a detection signal, and scans a beam to detect the azimuth of a target from changes in received signal strength. For example, in Japanese Unexamined Patent Application Publication No. 2000-180532, changes in received signal strength in the azimuthal direction are determined. When the pattern of the changes in the received signal strength includes a chevron, the azimuth at which a peak of the received signal strength occurs is detected as the target azimuth.

However, this detecting method of the target azimuth based on the chevron pattern formed in the changes in the received signal strength (a signal-strength profile) generated by the beam scanning cannot detect the azimuth of a target that does not cause a chevron in the signal-

strength profile. For example, when a target exists at an azimuth of the outermost angle in the scanning angular range of the beam, only one side of a chevron is formed. Moreover, when a target exists outside and adjacent to the outermost angle where the azimuth can be detected in a beam width, only a part of a chevron is formed in the signal-strength profile. In both cases, however, only a "shadow" of the target located outside the scanning angular range is cast in the scanning angular range, and the position of the peak in the signal-strength profile cannot be detected. As a result, the target azimuth cannot be detected.

It is an object of the present invention to provide a radar that can detect target azimuths located outside and adjacent to a scanning angular range of a beam.

Disclosure of Invention

To achieve the above-described object, according to the radar of the present invention, when a target exists adjacent to a predetermined scanning angular range, a signal-strength profile having part of a convex adjacent to the outermost angle in the scanning angular range is determined. The present invention is characterized in that the approximate target azimuth is estimated from this signal-strength profile. Accordingly, the target azimuth can be detected beyond the scanning angular range.

Moreover, the present invention is characterized in that the target azimuth is estimated from a ratio between received signal strengths at at least two beam azimuths. Accordingly, the target azimuth can be estimated with a small amount of data and with a simple calculation.

Furthermore, the present invention is characterized in that the reflectivity of the target is determined on the basis of the ratio between the received signal strengths at the two beam azimuths and the directional characteristic of an antenna. Accordingly, not only the azimuth but also the approximate size can be detected for a target outside and adjacent to the outermost angle in the scanning angular range.

In addition, the present invention is characterized in that the target azimuth is estimated from the number of beams having received signal strengths exceeding a threshold level and from the received signal strength of at least one of the beams in an azimuth range of half of a beam width, from the outermost angle, having antenna gains exceeding a predetermined threshold level. Accordingly, the target azimuth adjacent to the scanning angular range can be estimated with a simple process.

Brief Description of the Drawings

Fig. 1 is a block diagram illustrating the structure of

a radar according to a first embodiment.

Fig. 2 illustrates a directional characteristic of an antenna of the radar.

Fig. 3 illustrates the directional characteristic of the antenna plotted on Cartesian coordinates.

Fig. 4 illustrates the relationship between the azimuthal angle of the antenna and the gain and the like.

Fig. 5 illustrates the layout of a scanning range of a beam and the position of a target.

Fig. 6 illustrates an example of changes in received signal strength as a function of the azimuthal angle of the beam.

Fig. 7 illustrates changes in differences of received signal strengths between the outermost beam and the second outermost beam when the target azimuth is varied.

Fig. 8 illustrates the relationship of differences of the received signal strengths between the outermost beam and the second outermost beam.

Fig. 9 illustrates an example of the number of beams having received signal strengths exceeding a threshold level.

Fig. 10 illustrates the relationship among the number of beams having the received signal strengths exceeding the threshold level, the received signal strength of the outermost beam, and the estimated azimuth of the target.

Best Mode for Carrying Out the Invention

The structure of a millimeter-wave car-mounted radar according to an embodiment of the present invention will now be described with reference to the drawings.

Fig. 1 is a block diagram illustrating the structure of the radar. In Fig. 1, the element 1 is an RF block and the element 2 is a signal-processing block. The RF block 1 transmits and receives a millimeter-wave detection radio wave, and outputs a beat signal between a transmitted wave and a received wave to the signal-processing block 2. A modulation counter 11 in the signal-processing block 2 counts for finally generating a triangular wave from a D/A converter 10, and outputs the value to the D/A converter 10. The D/A converter 10 converts the count value into an analog voltage signal, and provides the signal to a voltage-controlled oscillator (VCO) 8 in the RF block 1. Herewith, the transmitted wave is frequency-modulated. The signal oscillated by the VCO 8 is supplied to a primary radiator 4 via an isolator 7, a coupler 6, and a circulator 5. This primary radiator 4 is disposed at a focal plane or adjacent to the focal plane of a dielectric lens 3. The dielectric lens 3 focuses the millimeter-wave signal radiated from the primary radiator 4 into a sharp beam. The primary radiator 4 and the dielectric lens 3 form an antenna.

When a reflected wave from a target, such as a vehicle,

enters the primary radiator 4 via the dielectric lens 3, the received signal is sent to a mixer 9 via the circulator 5. The received signal and a local signal that is a part of the transmitter signal from the coupler 6 are input to the mixer 9, and a beat signal having a frequency corresponding to the frequency difference between the received signal and the local signal is output to an A/D converter 12 in the signal-processing block 2 as an intermediate-frequency signal. The A/D converter 12 converts the signal into digital data. A digital signal processor (DSP) 13 performs a fast Fourier transform (FFT) on the data stream input from the A/D converter 12 to calculate the relative distance and the relative speed of the target, and outputs them to a host via an output circuit 15.

The element 16 in the RF block 1 is a scanning unit translating the primary radiator 4 in the focal plane of the dielectric lens 3 or in a plane parallel to the focal plane. A 0-dB coupler is formed between the moving portion including the primary radiator 4 and the fixed portion. The element M is a driving motor for the scanning unit 16. A beam is scanned by this motor, for example, within a range from -10.0° to $+10.0^\circ$ in steps of 0.5° at intervals of 100 ms.

The element 14 in the signal-processing block 2 is a microprocessor unit controlling the modulation counter 11

and the scanning unit 16. This microprocessor unit 14 orients the beam azimuth to a predetermined angle using the scanning unit 16, and determines a count interval while the scanning unit 16 is standing still such that the VCO 8 modulates in a range of one wavelength including an upslope and a downslope of a triangle wave.

Fig. 2 illustrates a directional characteristic of the above-described antenna. The symbol o indicates the position of the antenna, and the symbol P indicates a pattern of the directional characteristic. In this pattern, the lengths in the direction of radiation from the position o, which is defined as 0, illustrate the gain of the antenna.

Fig. 3 illustrates the directional characteristic of the antenna shown in Fig. 2 plotted on Cartesian coordinates. The horizontal axis is the beam azimuth, and the vertical axis is a relative gain when the gain at the azimuth of 0°, i.e. the forward direction, is defined as 0 dB. For example, the relative gain is -5 dB for a beam azimuth of +2° or -2°, and the relative gain is -18 dB for a beam azimuth of +4° or -4°. When signals having higher received signal strengths than a threshold level of the relative gain of -27.5 dB are defined as signal components, signals having lower received signal strengths are defined as noise components, thereby one beam has a width ranging from -5° to +5°, i.e. 10°.

In a known technology, changes in the received signal

strength as a function of the beam azimuth are determined as a signal-strength profile, and the azimuth of the maximum strength in a distribution of a series of the received signal strengths is simply determined as the target azimuth. For example, when the scanning angle ranges from -10° to +10°, targets located at a range from -15° to -10° are recognized as if all of them were located at -10°, and targets located at a range from +10° to +15° are recognized as if all of them were located at +10°.

However, the ratio between the received signal strength obtained from the outermost (in terms of angle) beam in the scanning angular range of the beam and the received signal strength obtained from a beam one beam or a plurality of beams inside the outermost beam is determined by the azimuth of a target located adjacent to the outermost angle and outside the outermost angle. Accordingly, the target azimuth can be estimated by determining this ratio between the received signal strengths.

Fig. 4 is a numerical table corresponding to the characteristic shown in Fig. 3. "Relative gain of transmitted-received beam" herein means a dB difference between the relative gain of a transmitted signal and the relative gain of a received signal when the beam azimuth varies in the scanning angular range of the beam. Accordingly, the value is twice as large as the "relative

gain". Furthermore, the "gain difference from beam 0.5° inside" is a dB difference between the above-described "relative gain of transmitted-received beam" and that of a beam 0.5° inside the outermost position.

Fig. 5 illustrates the layout of a scanning angular range of a beam and the position of a target located outside and adjacent to the outermost angle. In this embodiment, the target is located at an azimuth of +12° that is +2° outside the outermost angle of 10°.

Fig. 6 illustrates an example of changes in the received signal strength as a function of the beam azimuth. As illustrated, the received signal strength increases as the beam azimuth approaches the outermost angle of 10.0°, and this signal-strength profile is part of a convex.

As in this example, when the scanning angular range from -10° to +10° is scanned in angular steps of 0.5°, the relative gain of the transmitted-received beam to the target located at +12° is -10 dB, as shown in Fig. 4, since the target is located at a position of +2° relatively to the beam of +10°. Furthermore, since this target is located at an azimuth of +2.5° relatively to the beam of +9.5°, the relative gain of the transmitted-received beam is -15 dB. Therefore, the ratio (the difference in dB) between both of the received signal strengths is 5 dB.

When this relationship is used, the target azimuth can

be estimated with the ratio between the received signal strength of the beam at the outermost angle of 10.0° and the received signal strength of the beam at 9.5°.

Fig. 7 illustrates an example of changes in the ratios of the received signal strengths between the outermost beam and the second outermost beam when the target azimuth is varied among three different values, namely, 11.0°, 12.0°, and 13.0°. As described above, when the target azimuth is 12°, the ratio between the above-described received signal strengths is 5.0 dB. On the other hand, the ratio between the signal strengths is 3.0 dB for the target azimuth of 11.0°, and the ratio between the signal strengths is 7.0 dB for the target azimuth of 13°.

Fig. 8 illustrates the ratios of the received signal strengths between the outermost beam on the plus side (+10.0°) and the second outermost beam (+9.5°) derived from Fig. 4. In the above-described example, since the ratio of the received signal strengths between the outermost beam and the second outermost beam is 5 dB, the estimated target azimuth is +12° from Fig. 8.

The positive azimuth is illustrated in Fig. 8, however, the same result is achieved for the negative azimuth.

Furthermore, when these relationships are used, the received signal strength can be estimated on the assumption that a beam is radiated to a target located at an estimated

azimuth. When the target azimuth is 12.0°, the relative angle to the outermost angle of 10.0° is 2.0°, and the relative gain of the transmitted-received beam is -10 dB according to Fig. 3 compared to a case when the beam azimuth is the outermost angle of 10.0°. Consequently, if a beam is radiated in the direction of 12.0°, a received signal having a strength 10 dB higher than the received signal strength detected when the beam azimuth is 10.0° will be detected. In this manner, the received signal strength when the beam is directed to the beam azimuth and a scattering cross-section can be estimated from the received signal strength of the outermost beam. In other words, the approximate size of the target can be detected. The term "scattering cross-section" herein means the radio-wave reflectivity of the target converted into a cross-section of a sphere πr^2 (m^2), where r (m) is radius of the sphere. For a millimeter-wave radar, the scattering cross-section is about 10 (m^2) for a vehicle, and is about 1 (m^2) for a bicycle.

Next, a radar according to a second embodiment will now be described. The structure of the hardware is the same as that of the first embodiment.

The width of the azimuthal directions having antenna gains exceeding a predetermined threshold level is defined as a beam width, and a beam scans at angular intervals narrower than the beam width. At this time, if a target

exists outside the outermost angle, the received signal strengths of a plurality of beams located inside the outermost angle exceed a predetermined threshold level.

The radar according to the second embodiment estimates the target azimuth on the basis of the number of these beams and the received signal strengths.

Fig. 9 illustrates an example of changes in the received signal strength as a function of the beam azimuth. As illustrated, the received signal strength increases as the beam azimuth approaches the outermost angle of 10.0°, and this signal-strength profile forms part of a convex.

In this example, the number of beams having received signal strengths exceeding the threshold level is four including the beam at the outermost angle of 10.0°.

For example, when a beam is scanned within a range from -10.0° to +10.0° in 41 steps at intervals of 0.5°, the beams exceeding the threshold level are numbered #1, #2, #3, ... from the inside, and the received signal strength ΔP (dB) that exceeds the threshold level is determined. Fig. 10 illustrates the relationship among the above-described beam number, the received signal strength ΔP, and the target azimuth.

For example, when the number of beams having a received signal strength exceeding the threshold level is four and the received signal strength ΔP of the outermost beam (#4)

is 20 dB, the estimated target azimuth is in a range from 11.5° to 12.0°.

According to the present invention, when a target exists adjacent to a predetermined scanning angular range, a signal-strength profile having part of a convex adjacent to the outermost angle in the scanning angular range is determined. Since the approximate target azimuth is estimated from this signal-strength profile, the target azimuth can be detected beyond the scanning angular range.

Moreover, according to the present invention, since the target azimuth is estimated from a ratio between received signal strengths at at least two beam azimuths, the target azimuth can be estimated with a small amount of data and with a simple calculation.

Furthermore, according to the present invention, since the reflectivity of the target is determined on the basis of the ratio between the received signal strengths at the two beam azimuths and the directional characteristic of the antenna, not only the azimuth but also the approximate size can be detected for a target outside and adjacent to the outermost angle in the scanning angular range.

In addition, according to the present invention, since the target azimuth is estimated from the number of beams having received signal strengths exceeding a threshold level and from the received signal strength of at least one of the

beams in an azimuth range of half of a beam width, from the outermost angle, having antenna gains exceeding a predetermined threshold level, the target azimuth adjacent to the scanning angular range can be estimated with a simple process.

Industrial Applicability

As stated above, the radar according to the present invention can detect the target azimuth beyond the scanning angular range, and is useful for, for example, millimeter-wave car-mounted radar.